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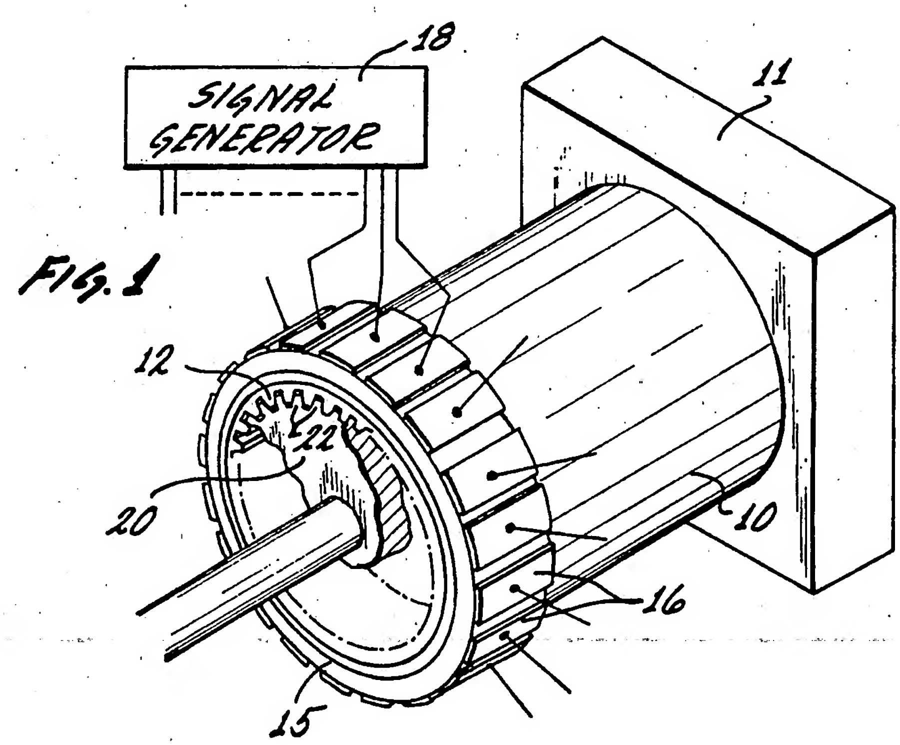
(54) High speed, high response drive

(57) An elastically deformable sleeve 10 is provided with an internal ring gear 12 and carries annularly arranged piezo-electric "bender" elements 15, 16 which are energized with high frequency voltage from a signal generator 18 to obtain a rotating elliptical deformation of the sleeve 10. The internal sleeve teeth 12 mesh with the teeth 22 of a rotor 20 at the short axis of the ellipse; the number of teeth 12 of the ring gear and of the rotor 20 differ so that upon rotation of the axes of the elliptical deformation the rotor 20 turns synchronously ar a reduced rate. The drive can be operated in a slewing mode or in a stepping mode. Application to positioning, movement, displacement and deformation of laser mirrors is exemplified.



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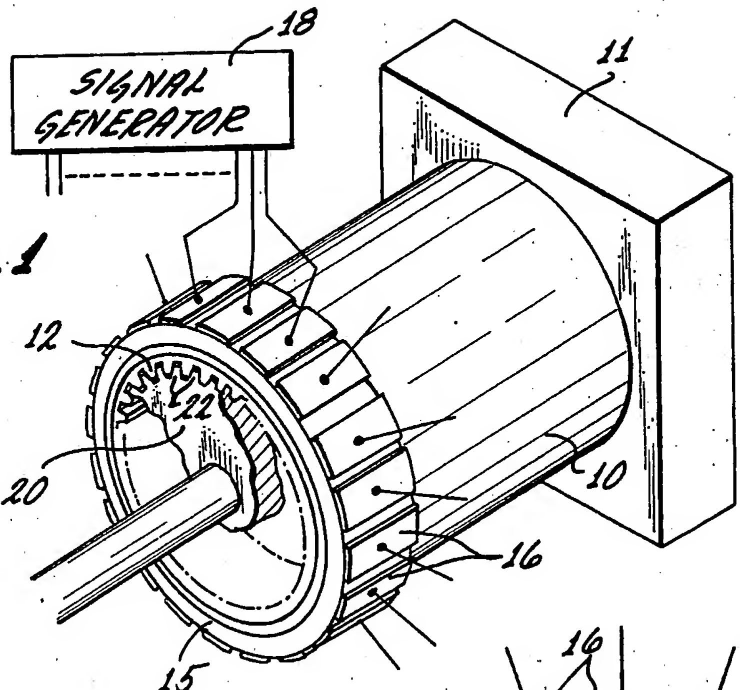

FIG. 1

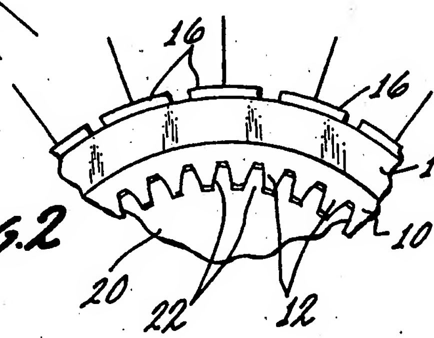

FIG. 2

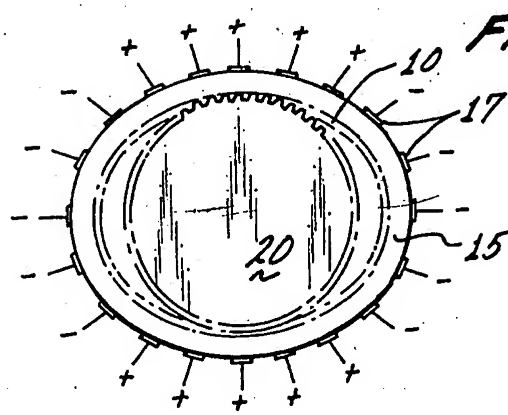

FIG. 3

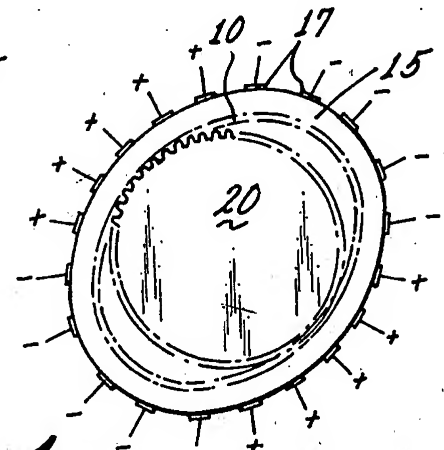

FIG. 4

SPECIFICATION

High speed, high r sponse drive

The present invention relates to a high speed, high response drive, "high speed" meaning, for example, several million rpm's of input velocity and several tens of thousands rpm's of output velocity.

The generation of precision movement and displacement is a persistent problem in many fields. The problem is clearly compounded if the movements and displacements are to occur at a high speed (bandwidth). A typical field of application is the positioning, movement, displacement, and deformation of laser mirrors. Such a mirror must, usually, provide a highly parallel beam (coplanar wave fronts). Undesired wave front perturbations are caused, for example, by atmospheric turbulence, and by density variations in the laser cavity along with structural vibrations. These perturbations frequently occur at a high rate (bandwidth in the kilohertz range and above). Corrective mechanical motion applied to the mirror must, thus, be capable of following these high-rate displacements. Corrective motion must have the desired rate or speed and must be sufficiently precise.

In a preferred embodiment of the present invention, an annular arrangement of piezoelectric "bender" elements is provided on an internally splined deformable sleeve co-operating with a rotor or spline gear for harmonic drive operation, the gear teeth being selected accordingly. The "bender" elements are provided with electrodes which are driven by a suitable signal generator. During operation, the generator energises some "bender" elements electrically in one direction, the others in the opposite direction, so that the sleeve is deformed elliptically. Accordingly, sleeve and rotor gears engage adjacent to the short axis of the ellipse, but are out of engagement adjacent to the long axis. The energisation pattern is progressively changed, causing the elliptical deformation to turn. If the axes of the ellipse have made one revolution, the rotor has turned by an angle given by the gear ratio. This drive has an advantage that the elliptical deformation of the sleeve (i.e., the energisation pattern) can be made to rotate at a very high speed, any constraint being given by the electronic components involved in the generation, and by the structural resonance of the piezo-electric devices involved. It is a particular feature of this drive that it is free of "back emf" effects. Th se eff cts severely limit the response of electromagnetic drives. The drive is, basically, of the stepping variety, a step being given by a change in the energization patt rn of the "bender" elements. A regular peripheral change in such a pattern, e.g. by means of sinusoidal energization voltag s, results in a continuous slewing motion, wherein, however, any particular position can be instantaneously attained and held. As far as the stepping mode is concerned, the number of different steps per rotor revolution is given by the number of "bender" elements, multiplied by the gear ratio; typically, the ratio will be several hundred-to-one. Such a drive is capable of a high speed, precision operation, as will be explained by way of example.

The invention will now be described in more detail, solely by way of example, with reference to the accompanying drawings, in which

Figure 1 is a perspective view of a drive in accordance with a preferred embodiment of the invention;

Figure 2 is an enlarged front elevation of a portion of the drive shown in Fig. 1; and

Figures 3 and 4 are schematic illustrations of the elliptical deformation of a part in the drive shown in Figs. 1 and 2, and of how the orientation of that deformation changes.

In the drawings, Fig. 1 shows a tube or sleeve 10 extending from a suitable support 11 in cantilever fashion. The tube or sleeve 10 is made of a suitable elastic material and is flexible; that is to say, the sleeve is amenable to undergo a flexible deformation, changing, for example, from a circular contour to an elliptical one. Except for the deformation, the sleeve 10 is stationary.

The front end of the sleeve is provided with gear teeth 12, co-operating and meshing with teeth 22 of a rotor 20. Unlike the sleeve 10, the rotor 20 is not flexible or deformable. In accordance with the usual rule underlying harmonic drives, the rotor has one or more teeth more or less than the number of teeth 12 of the gear in the sleeve.

The sleeve 10 carries, on its outside, a plurality of piezoelectric "bender" elements. These "bender" elements include common ceramic ring 15 which, in turn, carries a plurality of outer electrodes 16, e.g., twenty, or thereabouts. The sleeve 10 serves as a common inner electrode. Each "bender" element is, thus, defined by a segment of the piezoelectric ring 15 and by the adjoining electrodes, defining a pair of oppositely positioned electrodes, one from the plurality 16, the other one being the sleeve 10. The PZT-ring is bonded to sleeve 10 and to the electrodes.

All electrodes are connected to a signal generator 18, providing to the electrode faces of the "bender" element assembly suitable energizing signals. The signal g nerator 18 provides, for example, oscillations at a particular frequency, which is exactly the same for all of the electrodes, but whose phases differ, as will be explained with reference to the description of the slew mode. The generator 18 may alternatively provide step signals, being of different polarity as applied to different

on s of the electrodes.

The aim of the operation of the piezoelectric device 10, 16 and 15 as a whole is the generation of an elliptical deformation of sleeve 10 adjacent to its splined portion, defined by the teeth 12. This elliptical deformation causes those of the teeth 12 which are disposed near the short axis of such an ellipse to be in full, meshing engagement with the respective juxtaposed teeth 22 of the rotor, while those of the teeth 12 which are, at that instance, located adjacent to the long axis of the ellipse are disengaged from the rotor and its gear.

The elliptical deformation of the sleeve 10 results from the electrical potentials as applied in any instant to the electrodes and at particular polarities. Fig. 3 shows, by way of example, but on an exaggerated scale, the deformation of the sleeve 10. Moreover, the polarity values placed adjacent to the outer electrodes denote signal polarities as applied (radially) across the piezoelectric ring. A positive polarity, at the outer electrodes, tends to force the sleeve radially inwardly, while a negative polarity tends to force the sleeve radially outwardly. These individual energizations of portions of the ring 15 produce an overall elliptical deformation of that ring and of the sleeve 10.

As the polarities of some of the electrodes are altered, the ellipse is changed (rotated) as regards the orientation of its axes, as shown in the change from Fig. 3 to Fig. 4. This change in orientation of the elliptical deformation changes the engagement pattern of the sleeve and rotor teeth, thereby tending to cause the rotor to be angularly displaced in the same direction in which the ellipse is "rotated". After one full "revolution" of the ellipse (sleeve 10 itself does not rotate), the engagement pattern of stator and rotor has shifted by one tooth, and rotor 20 has been turned by the corresponding angular increment. In the "slew" mode, if f is the frequency of the ac voltage as applied, the ellipse will make one turn per two cycles; i.e., it will rotate at the speed $f/2$. Moreover, the ellipse rotates continuously, and rotor 20 will turn at a rate that is given by the speed reduction of the harmonic drive.

If the number of teeth of the sleeve is n while the number of teeth of the rotor is $n + 1$, then $f/2n$ is the number of revolutions of the rotor per unit time in which the frequency is expressed.

The resonance frequency for this PZT-ring 15, as supported by sleeve 10 and rotor 20, may approach the resonance frequency of a single "bender" element as defined by a PZT-ring s gment and the adjoining electrodes. By way of example, the piezoceramic ring may be made of a "GULTON" G-1512 material. A ring with a 2-inch diameter and twenty electr des exhibits a

$$\frac{59 \times 20}{\pi \times 2},$$

or 188 kHz resonance frequency.

This frequency when selected as an operating frequency for the piezoelectric ring, corresponds to a rotational input velocity of just under 6 million rpm of the ellipse. For $n = 200$, the rotor may thus make 28,200 rpm. The particular advantage of this high speed device flows from the fact that the motion occurs in precise synchronism with the energizing field because there is no back emf as in electromagnetic devices. This means that the rotor can drive an actuator through very precise positions, as controlled by the input operating at a high frequency which is equivalent to a high input velocity and a high rate of clock excapement. The input velocities are so high that high output velocities are still attainable, thus providing the desired precision at high bandwidth operation. This is particularly the case if the device is operated in the stepping mode; but also in the slew mode if the ac energization is interpreted as an energization by a particular, i.e., metered, plurality of cycles. The rotor will stop in any desired position.

As far as the stepping mode is concerned, the resonant frequency for the stepping modes is 1/10 of the slew mode; or 9400 "revolutions" of the ellipse per second. The precision in the stepping mode is the result of the construction and does not depend upon any feedback for position and/or speed control. The actuator on the output side, as connected to rotor 20, follows the motion thereof in an open-loop operation.

A single step can be defined by a change in energization, in which the four "boundaries" between the positively and negatively energized electrodes are shifted (rotated) by one electrode pair. In the case of twenty "bending" elements, this amounts to a turn of 18 degrees. If n is the assumed speed reduction of the drive, $20n$ is the number of steps per rotor revolution which the device can make. Let $n = 200$, the device may make 4000 steps per rotor revolution. Moreover, the device can reverse direction for each step.

As far as actuator speed is concerned, it may be assumed that each rotational step by rotor 20 is equivalent to a 2-micro-inch linear actuator displacement. In the stepping mode, the actuator velocity will, thus, be 188,000 $\times$ 2 microinches $=$ 0.376 inch per second. In the slew mode, the speed is ten times the step speed, i.e. 3.76 inches per second. It should be recalled that two cycles of the energizing voltage are required per "revolution" of the sleeve.

The voltage changes on the respective electrodes participating in a single-step pattern

change should not be of the step function type, but should have a ramp-shaped contour in order to obtain well-defined acceleration and deceleration whenever slew and step modes are combined in this way. The last wave of a train of ac signals should, thus, decay gradually. If the resonance conditions are observed, slew and step modes can be combined in that a definite sequence of a slew mode type ac cycle defines a long "step", causing the drive to move through a definite number of single steps, but at the slew mode rate.

Although the ring 15 described hereinbefore is of piezoceramic material, other embodiments can be constructed in which other piezoelectric material, not necessarily a piezoceramic, is used to provide the bender elements.

CLAIMS

1. A high speed, high response drive, comprising:

an annular, deformable, internal ring gear;

a plurality of piezoelectric bender elements on the ring gear, being annularly arranged;

control means connected to the elements to deform them so as to obtain an elliptical or near-elliptical deformation of the ring gear; and

a rotor element with an external gear, the number of teeth of the element differing from the number of teeth of the ring gear by one or more, the gear of the rotor element engaging the ring gear along a small axis of the ellipse while being disengaged therefrom along a long axis of the ellipse so that, upon rotation of the axes of the ellipse due to a change in the energization pattern as provided bu the control means, the rotor element is synchronously turned with the rotation of the axes of the ellipse.

2. A drive according to Claim 1, wherein the plurality of piezoelectric elements includes a common, piezoelectric ring and discrete electrodes.

3. A drive according to Claim 1, wherein the control means includes a signal generator connected to electrodes of the elements to provide thereto ac signals at the same frequency but at different phases.

4. A drive according to Claim 1, wherein the control means includes a signal generator providing a sequence of discrete signal levels to electrodes of the bender means.

5. A high speed, high response device, comprising:

an elastic sleeve having an internal gear; and

piezoel ctric bender means disposed on the sleeve and capable of indivisual en rgization to, thereby, deform the sleeve elliptically, a change in en rgization pattern of the bender m ans resulting in a change in ori ntation of the axes of the ellips , the internal gear of the spline engaging the rotor gear along the short axis but not al ng the l ng axis of the ellipse.

6. A device according to Claim 5, wher in control means rovides a signal pattern in each instant to the plurality of devices, and different patterns in sequence, whereby the energization of said bender means is changed from pattern to pattern.

7. A drive according to Claim 1 and substantially as described hereinbefore with reference to the accompanying drawings.

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